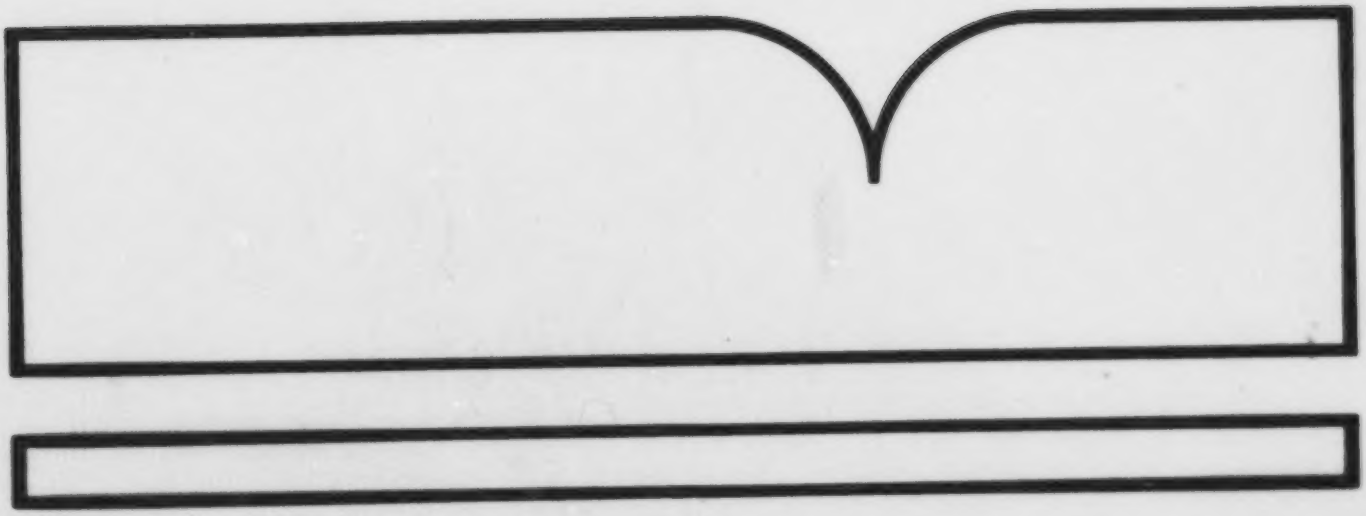
PB83-131193

Effect of Elevated Water Temperature on Macro-Invertebrate Communities in Outdoor Experimental Channels

(U.S.) Environmental Research Lab.-Duluth
Monticello, MN

Jan 82



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completi

1. REPORT NO.	2.	3.
EPA-600/J-82-244	Journal Article	PB83-131193

4. TITLE AND SUBTITLE	5. REPORT DATE
Effect of Elevated Water Temperature on Macro-Invertebrate Communities in Outdoor Experimental Channels	1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Arthur, J. W., J. A. Zischke, and G. L. Erickssen	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Monticello Ecological Research Station P.O. Box 500 Monticello, Minnesota 55362	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-2453
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Environmental Research Laboratory-Duluth 6201 Congdon Boulevard Duluth, Minnesota 55804	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/03

15. SUPPLEMENTARY NOTES
Water Res. 16: 1465-1477 (1982)

16. ABSTRACT

Macroinvertebrates were sampled monthly from December 1976 to September 1977 in two 520 m long outdoor experimental channels. One channel was maintained at ambient seasonal Mississippi River water temperatures and the other 10°C higher. Maximum water temperature reached 31.0°C in the ambient and 40.8°C in the heated channel. Elevated temperature seasonally altered macroinvertebrate abundance and life history in the channels. Few animals were found in the heated channel during the period of maximum water temperature. Most macroinvertebrate density and composition differences were confined to the channel riffles rather than the pools. Peak total density in the heated channel riffles occurred 3 or 4 weeks before the ambient channel. Total macroinvertebrate density was appreciably higher in the heated channel riffles during the winter and spring months and in the ambient channel riffles during the summer months. This seasonal alteration was due to composition differences of several identified taxa. Reproductive periods for one snail and one isopod species began approximately 2 and 3 months earlier in the heated channel than in the ambient channel. No marked change occurred in the reproductive activities of an amphipod in the two channels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	14
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA-600/J-82-244
JOURNAL ARTICLE

Water Res. Vol. 16, pp. 1465 to 1477, 1982

EFFECT OF ELEVATED WATER TEMPERATURE ON MACROINVERTEBRATE COMMUNITIES IN OUTDOOR EXPERIMENTAL CHANNELS

JOHN W. ARTHUR[1], JAMES A. ZISCHKE[2] and GERALD L. ERICKSEN[2]

[1]Monticello Ecological Research Station, U.S. Environmental Protection Agency, P.O. Box 500, Monticello, MN 55362 and
[2]St Olaf College, Northfield, MN 55057, U.S.A.

(*Received January* 1982)

Abstract—Macroinvertebrates were sampled monthly from December 1976 to September 1977 in two 520 m long outdoor experimental channels. One channel was maintained at ambient seasonal Mississippi River water temperatures and the other 10°C higher. Maximum water temperature reached 31.0°C in the ambient and 40.8°C in the heated channel. Elevated temperature seasonally altered macroinvertebrate abundance and life history in the channels. Few animals were found in the heated channel during the period of maximum water temperature. Most macroinvertebrate density and composition differences were confined to the channel riffles rather than the pools. Peak total density in the heated channel riffles occurred 3 or 4 weeks before the ambient channel. Total macroinvertebrate density was appreciably higher in the heated channel riffles during the winter and spring months and in the ambient channel riffles during the summer months. This seasonal alteration was due to composition differences of several identified taxa. Reproductive periods for one snail and one isopod species began approx. 2 and 3 months earlier in the heated channel than in the ambient channel. No marked change occurred in the reproductive activities of an amphipod in the two channels.

INTRODUCTION

Thermal effluents from power plants, as shown in Britain and the United States, have caused localized temperature elevations up to 10–11°C in receiving waters (Langford, 1972). Studies of macroinvertebrate communities below power plants have been conducted in both large and small river systems, and changes in drift, density, biomass, and diversity have been reported (Coutant, 1962; Durrett & Pearson, 1975; Miller *et al.*, 1976; and others). The principal disadvantage of these field studies was the inability to control flow and temperature in the system under study. Controlled thermal studies over a 6 month period were conducted in outdoor experimental channels in northern Alabama by Wrenn *et al.* (1979) at ambient and at 2, 4, and 6°C above ambient temperatures. Few consistent effects on macroinvertebrates were found although some insects showed accelerated life cycle development and amphipods displayed lower densities in the thermally elevated channels. Bush *et al.* (1974) in their review of thermal effects concluded that water temperatures safeguarding fishes will generally protect invertebrates. They also concluded that water temperatures exceeding 32°C would cause deviations in the normal composition of invertebrate communities.

The National Academy of Sciences & National Academy of Engineering (1973) suggested that future work in developing temperature criteria for aquatic life should be directed toward a population dynamics approach. The need for additional temperature effects information on macroinvertebrates led to this study in outdoor experimental channels at the U.S. EPA Field Station, Monticello, Minnesota. The purpose for constructing the outdoor systems was to investigate the influence of temperature on fish and their food chain and conduct field assessment studies on the accuracy of water quality criteria to protect aquatic life. This objective was followed during our studies in two experimental channels: one was maintained at ambient temperature and the other at 10°C above ambient. The distribution, abundance, population structure, and life history of macroinvertebrates in the two channels were compared over a 10-month period.

METHODS AND MATERIALS

Study site

The Monticello Ecological Research Station, a field station of the U.S. EPA Environmental Research Laboratory at Duluth, Minnesota, is located on 13.4 ha of land leased from the Northern States Power Company adjacent to the nuclear electric generating plant and the Mississippi river at Monticello Minnesota. The station has eight outdoor experimental channels each 520 m long and 0.14 ha in water surface area (Fig. 1). Each channel contains nine mud-bottomed pools (fine sandy loam to coarse sand substrate) and eight alternate gravel riffles. The pools are 30.5 m long, 3.6 m wide and 78–86 cm deep, and riffles constructed of 2–5 cm dia gravel, are 30.5 m long, 2.4 m wide and 10–20 cm deep. The dominant plants in the channels were the filamentous alga, *Hydrodictyon reticulatum*, and the macrophyte *Elodea canadensis*. Other common macrophytes were *Ceratophyllum demersum*, *Lemna minor*, and *Potamogeton crispus*, *P. nodosus*, and *P. pectinatus*. Macrophyte growth was largely confined to the pools.

Experimental test water was pumped from the Mississippi River at the power plant intake into two 14 cm dia

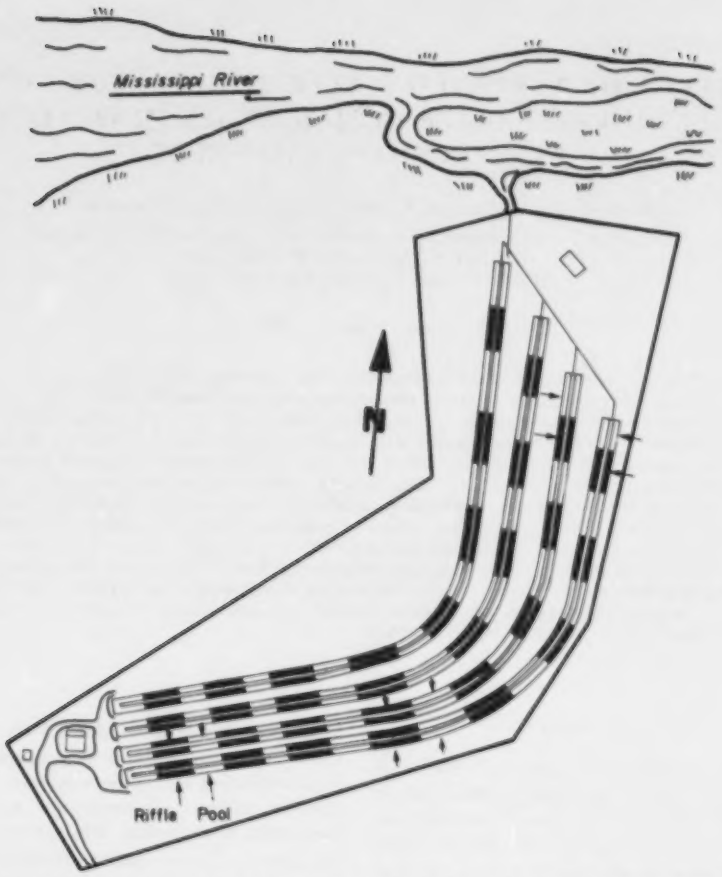


Fig. 1. Location and configuration of the outdoor experimental channels. Sampling sites indicated by an (→) arrow.

steel pipes. Water in one pipe was heated by passage through a heat exchanger in which warm power plant condensor water passed through the outer shell. Heated water and ambient-temperature water were mixed in the field station and conducted through pipes to the experimental channels. During the period of this study, 11 October 1976–13 September 1977, one channel (No. 5) was at ambient temperature and the other (No. 8) was maintained at 10°C above ambient. Flow rates in each channel averaged 2.3 $m^3 min^{-1}$ (range 1.7–2.4). Typical operating flow velocity across the riffles was 0.1–0.2 $m s^{-1}$ and approx. 0.02 $m s^{-1}$ in the pools (Stefan *et al.*, 1980).

Sampling procedures and analyses

Benthic macroinvertebrates were sampled at six locations (three riffles and three pools) in each channel with substrate-filled steel containers (Fig. 1). Each container had a 14.3 × 12.8 cm top opening, or about 0.02 m^2 of area, and was 15.0 cm deep. Two opposing sides of each riffle sampler were modified with 6 cm^2 holes covered with stainless steel screen (0.6 mm mesh) to serve as ventilating ports. The pool sampler was provided with a swivel handle to which a plastic bobber was attached to make location easier. Pool samplers did not contain the screened ventilation ports. All samplers were buried flush to the top of the substrate with the aid of a shovel in riffles and a post-hole auger in the pools. The samplers were left in place for 8 weeks to allow for a stable colonization period. A screened cover was attached to the top of the riffle samplers prior to removal by hand, and pool samplers were removed with a metal hook. Triplicate samples were taken from the upper, middle, and lower riffles and pools (Fig. 1) about every 4 weeks beginning 14 December 1976. Samplers were implanted in the channels each time a set was removed.

A screened box was used to separate macroinvertebrates from the riffle. Elutriators were used as separation device for the pool samples. The riffle gravel was spread across a 60 × 30 cm screened box (1.2 cm mesh), and the organisms were washed free into a wooden trough and concentrated onto 2.0, 0.8, and 0.4 mm mesh sieve screens. The elutriator was constructed for a commercial plexiglass fish egg hatching cyclinder, similar to the device described by Koosman & Newburg (1977), but modified with three 14 mm dia glass elbows inserted into the cyclinder 8, 16, and 24 cm from the top. Well water was introduced to the sampler at the bottom of the cylinder and as the washing continued, the side ports were opened in turn from the top down. The organisms leaving the ports were concentrated in 0.8 and 0.4 mm mesh sieves. Debris remaining in the elutriator was washed into sieves 10 times to remove any remaining organisms (usually mollusks). The entire washing process required two to three hours per sample.

All samples were concentrated in a 0.4 mm mesh sieve and preserved in 10% formalin containing 100 mg l^{-1} rose bengal stain. Each sample was separated into three fractions with the two larger fractions counted and sorted over a light box and the smallest fraction processed in a small glass sorting tray with a stereomicroscope (10× magnification). Isopods, amphipods, mayflies, and snails were indentified to genus or species and all other invertebrates to the family level. Oligochaetes were not counted in the samples.

A subsample procedure was used if more than 100 individuals of a taxon were present in the mesh fractions. Prior to subsampling, the less abundant forms were counted and removed from the coarse debris. A flatbottomed gridded glass dish with a surface area of 385 cm^2 served as the subsampling chamber. The sample was evenly dispersed with forceps, and five glass cylinders (each 7.6 cm^2) were randomly placed in the gridded chamber. Invertebrates within the five cylinders and any organisms under one-half of the cylinder's wall were removed with a modified 50 ml pipette. A 25% subsample was counted by this procedure. Repeated trials showed that accuracy was within 20% of the actual sample size.

Size frequency data were recorded for three of the most common macroinvertebrates in the channels. Body length of an amphipod (*Crangonyx pseudogracilis* complex), an isopod (*Asellus* r. *racovitzai*), and the snail (*Physa gyrina*) were measured to the nearest millimeter. Antennae, posterior appendages, and brood pouch young of the crustaceans were not measured. Size determinations were generally made only if at least 30 isopods and 100 amphipods and snails were present in the sample set. Too few amphipods and no isopods were present in the heated channel after June to permit comparisons.

Summaries of total numbers and percentages of each taxon and groups (e.g. crustaceans, insects, mollusks, etc.) in each channel location and sampling interval were obtained. The riffle data was separated from the pools due to differences in habitat. Taxonomic composition present in the two channels were compared using the "degree of similiarity" analysis given by Langford (1972). This procedure involved obtaining a percentage quotient by dividing the number of common taxa by the total identified taxa found in both channels.

For seasonal analyses, data were grouped by collection period: winter (November–February), spring (March–May), and summer (June–August). Only taxa that comprised 95% of the total in a given season were included. Actual count data were used because various standard transformations did not achieve normal distributional patterns and sometimes masked interactions between channels and locations within channels.

Two univariate statistical approaches were taken to compare macroinvertebrate distributions in the ambient and heated channels by season. Non-parametric tests were used because no assumptions regarding taxa distribution of means and variances were necessary (Elliott, 1971). The Mann–Whitney *U*-test was used for between channel comparisons and the Kruskal–Wallis test was used for comparing stations within the two channels. For both applications, no correction was made for ties in order to be conservative in declaring statistical significance. Analysis of variance was the parametric procedure employed (Neter & Wasserman, 1974). The control variables were channel and location. All differences were judged significant at $P < 0.05$ with both the nonparametric and parametric procedures.

The community structure within and between channels was further compared by principal component analysis (Nie *et al.*, 1975). Computer programs compiled by Nie *et al.* (1975) were used for the analysis. Clusters were identified for each channel by varimax rotation procedures, and eigenvalues greater than one were used to classify the taxa.

Both water and substrate temperature were monitored in the upper, middle, and lower riffles and pools throughout the study. Pool water temperatures were taken with type-T thermocouples at approx. 6–8 cm above the bottom and recorded continuously on Leeds and Northrup Speedomax W recorders. The water temperatures were recorded at three hour intervals and manually entered into a computer for summarizing according to procedures formulated by Stefan *et al.* (1980). Substrate temperatures were measured at surface and 15 cm into the pool mud and 8 cm into the riffle gravel at mid-day 2–3 times per week with a Leeds and Northrup 8690-2 mV potentiometer and type-T or Yellow Springs Instrument thermocouples.

Procedures for routine chemical water analyses were according to the APHA (1975). Dissolved oxygen and pH were usually analyzed weekly in the upper, middle, and lower pools at sunrise and 2–3 p.m. CST. The dissolved oxygen concentrations were measured in the ambient channel only once in February. Total hardness, alkalinity, and acidity analyses were performed weekly from the channel discharge water. Similar pH values were found in both channels with an overall range of 7.5–9.0. From March through August, less pH variation occurred in the upper (7.8–8.6) than in the lower pools (7.6–9.0). Total hardness and alkalinity ranged from 140 to 216 and from 124 to 200 mg l^{-1}, respectively. A variation of <1–16 mg l^{-1} was found for total acidity.

RESULTS

Physical and chemical characteristics

The heated channel was generally 8–10°C warmer than the ambient channel throughout the study. Power plant shutdowns during portions of December, February, and March caused mean water temperatures in the heated channel to decrease by 3–4°C for brief periods of up to 5 days (Fig. 2). During the study, mean temperatures in upper sections of the heated channel were 2–5°C higher than in the lower riffle and pool. Longitudinal temperatures in the ambient channel were more uniform, and within 1–3°C. Water temperatures in the ambient channel began to rise from the winter baseline in mid-March and exceeded 10°C by mid-April and 20°C from mid-May through August. Mean water temperature in the heated channel generally exceeded 20°C in mid-April and 30°C from late-May through early-August. The heated channel had a maximum water temperature of 40.8°C on 15 July compared to a maximum of 31.0°C in the ambient channel on 19 July. Maximum substrate temperatures in the ambient and heated channels were 28 and 39°C, respectively. Over the study, there was a 1–2°C difference between the heated channel substrates.

A greater range in dissolved oxygen was present in the lower than upper channel pools. The monthly range of dissolved oxygen (as percent saturation) was greater throughout the heated channel (46 and 214%) from November through March than in the ambient channel (66–149%, Fig. 3). Dissolved oxygen maximum and minimum concentrations were similar in both channels from April to August. The greatest range in percent dissolved oxygen saturation was 5–220 in the heated channel during June. Minimum early morning dissolved oxygen concentrations were less than 25% saturation in the lower ambient and

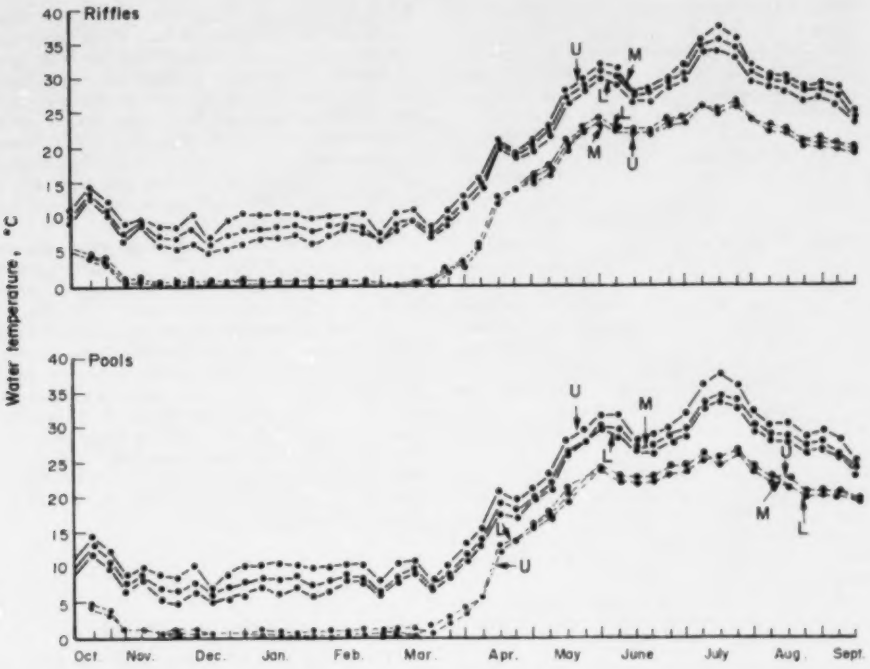


Fig. 2. Weekly mean water temperature in the upper (U), middle (M), and lower (L) riffles and pools in the ambient (-----) and heated (——) channel.

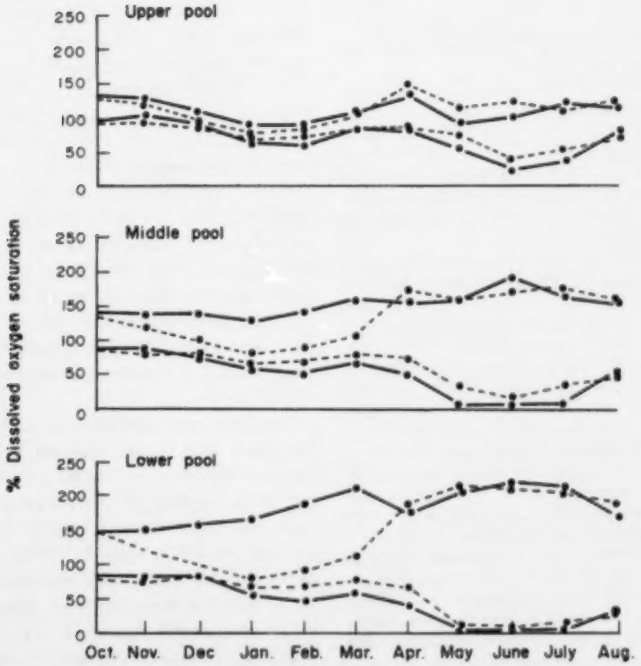


Fig. 3. Monthly maximum and minimum percent dissolved oxygen saturation in the upper, middle, and lower pools in the ambient (-----) and heated (——) channels.

middle and lower heated channel pools from May to June and in the upper end of the heated channel in June.

Community composition

The most common macroinvertebrates in the channels in decreasing order of average total abundance were: *Physa* snails, amphipods, chironomids, flatworms, *Caenis* sp., and *Callibaetis* sp. mayflies, isopods, *Gyraulus* sp. snails, and damselflies (Table 1). Leeches comprised more than 1% of the total benthic density during the summer as did ceratopogonids during the winter surveys. Flatworms, isopods, and amphipods were more abundant in the riffles; *Gyraulus* snails were more abundant in the pools. Crustaceans were at low densities in the ambient channel from late April–June and in the heated channel after mid-July. Isopods were not found in the heated channel surveys after June.

Macroinvertebrate density was markedly higher in the riffle sections, particularly in the ambient channel (Fig. 4). Highest density in the heated riffles (161,000 per m^2) occurred four weeks earlier than in the ambient riffles (260,000 per m^2). Lowest density in the heated riffles occurred during the period of maximum water temperature and in the upper channel section (200 per m^2). At this time, density increased with distance downstream to 7100 and 19,000 per m^2 in the middle and lower riffles, respectively. Lowest density in the heated pools occurred also during the period of maximum temperature elevation and at the upper end (200 per m^2). Lowest density in the ambient riffle and pools was in February and March with averages of 2300 and 660 per m^2, respectively.

Comparison of the macroinvertebrate taxa without regard to abundance is shown in Fig. 5. The two channels were generally more qualitatively similiar in the winter than in either the spring or summer months. The lowest degree of similarity (48–58%) occurred in the riffles and pools following the period of maximum water temperature.

Life history patterns

Size frequency analysis of *Physa gyrina* and *Asellus r. racovitzai* showed a shift toward late winter and early spring breeding in the heated channel (Figs 6

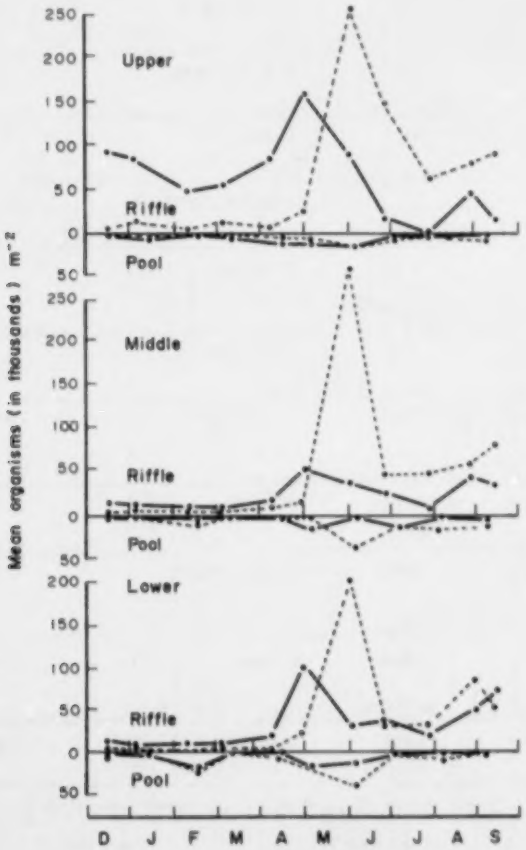


Fig. 4. Macroinvertebrate density in the upper, middle, and lower riffles and pools in the ambient (-----) and heated (——) channels.

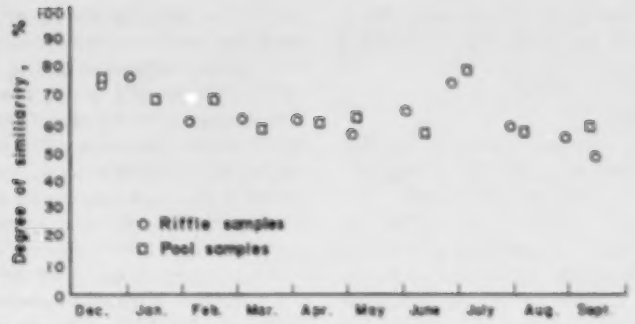


Fig. 5. Macroinvertebrates taxa similarity between ambient and heated channels.

and 7). During the winter months when more than 70% of the snails were adults (>7 mm) in the heated channel, only about 20% were adults in the ambient channel. The first newly-hatched snails were found in the heated channel in mid-April but not until early June in the ambient channel. A second generation of snails appeared in mid-August from the upper end of the heated channel, about one month earlier than in the ambient channel. A new generation of isopods first appeared in the heated channel in early February samples and in late May in the ambient channel.

Gravid *Crangonyx* sp. females (>5 mm) were

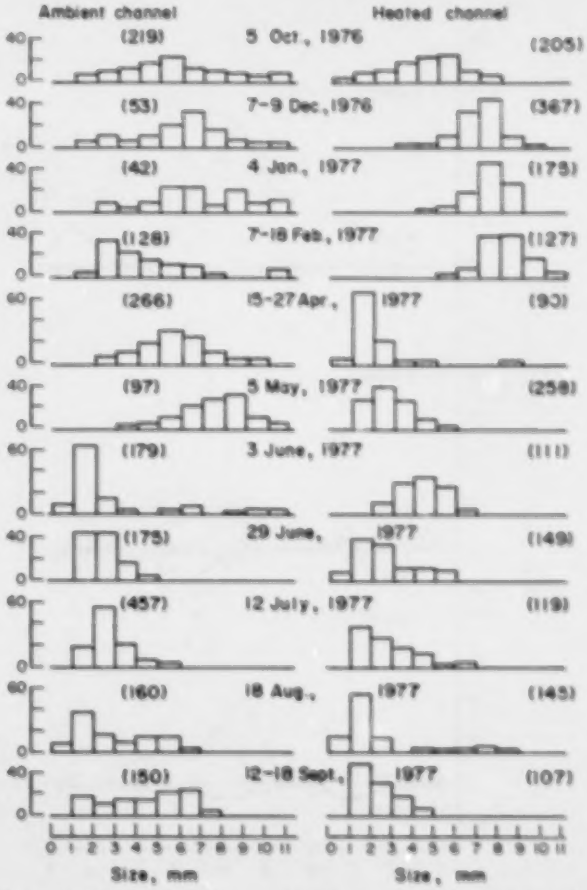


Fig. 6. Size distributions of *Physa gyrina*. Expressed as percentage of total within each size category, number in parenthesis represent individuals measured.

Table 1. Percent occurrence of common macroinvertebrates found in the ambient (A) and heated (H) channels

	Riffles																			
Animal Group	12 Dec.		4 Jan.		7 Feb.		4 Mar.		5 Apr.		27 Apr.		2 June		24 June		29 July		29 Aug.		13 Sept.	
	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H*
Planariidae	9	34	7	25	10	25	4	26	5	20	10	20	8	30	28	20	54	+	49	+	31	+
Hirudinea	–	–	+	+	–	–	–	–	+	–	+	–	+	+	1	+	4	1	+	+	+	+†
Isopoda	2	+	18	+	2	10	4	1	4	3	+	2	4	7	18	5	5	–	5	–	11	–
Amphipoda	30	42	30	56	20	41	42	50	16	36	8	21	2	44	16	8	20	+	35	+	40	1
Callibaetis	7	4	13	2	15	2	13	3	13	1	+	–	+	+	1	7	2	+	+	3	+	3
Caenis	9	1	6	+	10	1	2	1	7	3	15	1	2	+	1	+	6	13	2	15	7	29
Coenagrionidae	1	1	1	+	1	1	+	1	3	+	1	+	+	+	1	3	1	6	1	4	1	7
Chironomidae	17	7	9	7	30	9	30	7	29	4	42	23	26	1	4	8	3	11	3	22	5	21
Physa	19	10	13	8	8	10	3	9	12	31	17	33	50	16	25	45	3	63	5	53	4	32
Gyraulus	5	+	2	+	1	+	1	+	4	+	5	+	8	+	5	1	+	1	+	1	–	1
	Pools																			
	12 Dec.		13 Jan.		17 Feb.		10 Mar.		13 Apr.		3 May		8 June		1 July		4 Aug.		9 Sept.	
	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H
Planariidae	2	1	6	6	1	19	2	2	7	14	9	4	+	3	14	4	21	3	6	–
Hirudinea	–	1	–	1	–	+	–	4	–	–	+	+	+	1	7	1	11	16	1	1
Isopoda	+	+	–	–	+	+	–	–	1	+	–	–	+	+	1	–	3	–	4	–
Amphipoda	+	3	–	1	+	3	2	–	2	+	–	–	+	–	5	+	22	8	56	1
Callibaetis	3	3	1	1	29	+	5	–	+	–	–	+	+	+	1	+	1	2	+	+
Caenis	2	–	11	13	26	2	18	5	12	5	3	2	1	1	+	–	–	–	+	2
Coenagrionidae	+	9	+	1	1	4	1	2	5	1	1	+	+	4	2	4	1	4	6	7
Chironomidae	57	35	21	45	18	36	34	21	28	35	20	61	38	3	7	3	2	11	4	10
Ceratopogonidae	–	–	+	+	3	1	8	–	1	–	1	+	+	1	–	+	1	–	–	–
Physa	16	44	40	28	8	30	12	36	21	36	62	30	53	73	62	86	36	53	17	75
Gyraulus	16	2	18	3	13	1	15	39	24	3	4	2	7	13	2	1	1	3	+	–

*H refers to heated channel; A to ambient channel.
†+ refers to taxa <1%; – to taxa not found.

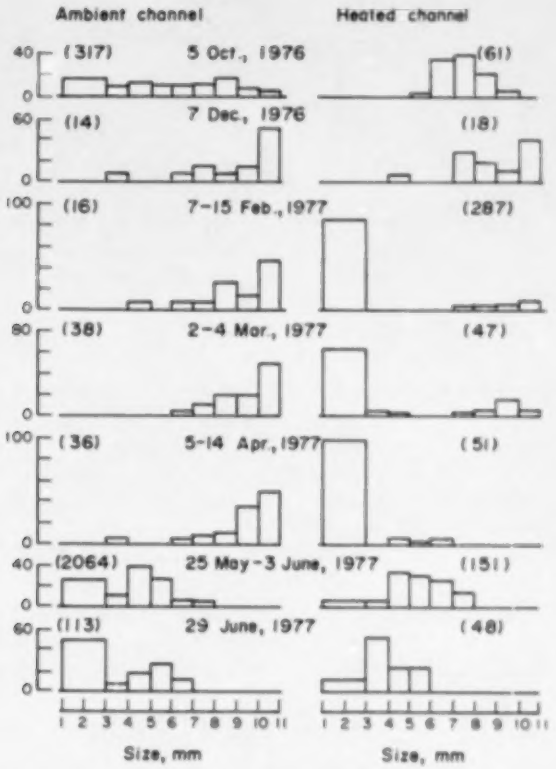


Fig. 7. Size distributions of *Asellus racovitzai*. Expressed as percentage of total within each category, number in parenthesis represent individuals measured.

generally present in both channels from December to May (Fig. 8). Although size frequency analyses did not reveal discreet cohorts, a large pulse of young was observed in the heated channel in early January and in early June in the ambient channel.

Seasonal and location differences

Distributional patterns of the macroinvertebrates were not uniform in the channels. More between channel significant density differences occurred in the riffles during the winter than in either the spring or summer. In the heated channel, five taxa were at higher densities ($P < 0.05$) during the winter and four taxa during the spring (Table 2). Four taxa were at higher densities in the ambient channel during the summer. Flatworms were the only organisms showing significant density differences between channels during all three seasons. Isopods, amphipods, chironomids, and physid snails showed significant between channel differences in two of the three seasons. Most within channel location differences were found in the heated channel during the winter and spring and in the ambient channel during the summer. Flatworms and crustaceans had higher densities in the upper heated riffle in the winter and spring seasons and *Caenis* mayflies in the lower heated riffle during winter and summer seasons.

Fewer seasonal and location differences were found in the pools (Table 2). Significant between channel differences were more pronounced in the summer season with higher densities of five taxa in the ambient channel. *Caenis* mayflies and *Gyraulus* snails had higher densities in the lower pools during the winter and spring. *Physa* snails were the only pool inhabitants showing neither a channel nor a location difference during all three seasons.

Principal component analyses indicated more macroinvertebrates coexisting together in the riffles than pools (Table 3). Flatworms, isopods, and amphipods were associated in the ambient riffles during each of the three seasons. Flatworms and amphipods formed another consistent association in both the ambient and heated riffles. Chironomids and *Physa* snails were closely associated in both the ambient and heated pools during the summer season. *Caenis* mayflies and *Gyraulus* snails were generally associated during the winter and spring in the ambient riffles and pools. *Caenis* and *Callibaetis* mayflies were within the same clusters in the heated riffles and ambient pools in the winter and heated riffle in the spring. Leeches and damselflies showed few consistent linkages.

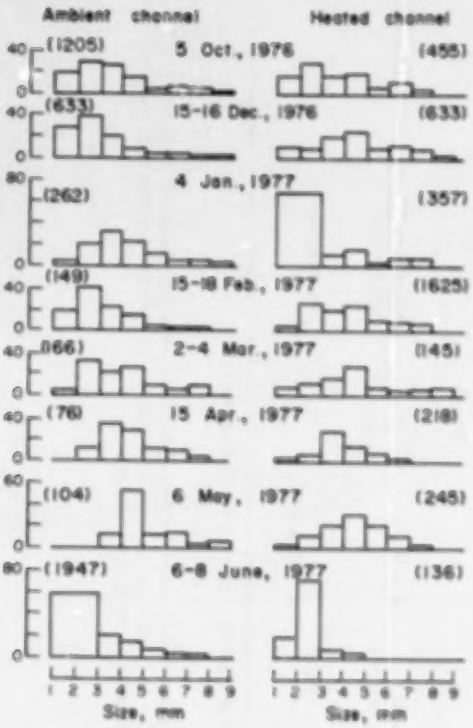


Fig. 8. Size distributions of *Cryptomyx pseudopractilis* complex. Expressed as percentage of total within each size category, number in parenthesis represent individuals measured.

DISCUSSION

The macroinvertebrates found in both channels were representative of a lentic community. Most of the dominate forms were herbivores-detritivores. Notably absent from the channels were larger shredders (stoneflies) and filterfeeding collectors (net-spinning caddisflies) although they were common in the Mississippi River (Hopwood, 1974) and in the water imported to the channels. River water was added to the channels on a sustained basis 1-year before this study was started. Chironomids initially colonized the channels followed by the snails (*Physa* and *Gyraulus*), isopods, amphipods, mayflies, and predaceous damselflies and flatworms. About 1 year was needed for the macroinvertebrates to attain a stable abundance and diversity.

Most macroinvertebrate distributional and density differences occurred in the riffle sections (Table 2). The upper riffle in both the ambient and heated channels were dominated by crustaceans and flatworms with the middle and lower riffles by insects. These differences may be related to detritus particle compositions within the gravel riffle substrate and import of allochthonous materials from the river water supply. Rabeni & Minshall (1977) concluded that the distribution of aquatic insects is primarily related to the availability of detritus. In their study, the substrate-particle size had greater influence on detritus distribution than current velocity or siltation. Gray & Ward (1979) have also shown that food availability and consumption are functions of particle size.

Large diel fluctuations in dissolved oxygen concentrations were observed in the lower sections of both channels with concentrations approaching zero during the summer months. Despite the low oxygen concentrations, insects continued to reside in the lower channel sections. Many insects have a high short-term tolerance (< 12 h) to dissolved oxygen concentrations less than 2 mg l^{-1} (Surber & Bessey, 1974). For example, several chironomid species are able to tolerate dissolved oxygen concentrations to 1 mg l^{-1} (Curry, 1965).

Peak macroinvertebrate density occurred 3–4 weeks earlier in the heated channel. The elevated temperature early in the year may have favored the development of an increased crustacean, flatworm, and snail abundance by creating a greater food supply by possibly stimulating plant growth. Wrenn *et al.* (1978) also observed an advanced peak density of about one-month in outdoor channels heated 4 and 6°C above ambient. However, they found few consistent significant differences in density or biomass for individual macroinvertebrate groups.

Marked declines in macroinvertebrate abundance have been found by others in outdoor systems at temperatures of 40–42°C (Coutant, 1962; Durrett & Pearson, 1972; Miller *et al.*, 1976). Lowest macroinvertebrate abundance occurred in the heated channel when the maximum temperature was 40.8°C in mid-July. *Caenis* mayflies, damselflies, chironomids, and physid snails were more common during the summer in the heated channel. By comparison, summer abundance in the ambient channel was appreciably higher in the riffle sections with flatworms, isopods, amphipods, and chironomids accounting for the difference. The macroinvertebrate population differences generally correspond with the classifications of tolerant and intolerant forms to elevated temperatures as summarized by Langford (1972).

Reproductive activities for the snail, *Physa gyrina*, began during the spring season in the heated channel. Newly-hatched snails were not found in the ambient channel until June. During these times, water temperature in the two channels were at 20–25°C. De Witt (1955) found temperatures of 10–12°C to be the minimum for *Physa gyrina* oviposition. Breeding occurred from April to early October with either one generation per year or two generations with incomplete replacement. Sankurathri & Holmes (1976) compared the life histories of *Physa gyrina* in shallow lake coves adjacent to a power plant in Alberta, Canada. Water temperatures in the heated cove were elevated 14°C in the winter and 8°C in the summer. Snails were significantly more abundant in the heated lake

Table 2. Seasonal and location macroinvertebrate density differences in the ambient and heated channels

Animal group	Winter			Spring			Summer		
	Channel	Ambient	Heated	Channel	Ambient	Heated	Channel	Ambient	Heated
				Riffles					
Planariidae	H > A	U > M, L	U > M, L	H > A	—	U > M, L	A > H	U > M, L	—*
Hirudinea		Not Analyzed	†		Not Analyzed		(A > H)‡	L > M, U	—
Isopoda	—	—	U > M, L	(H > A)	—	U > M, L	A > H	U > M, L	—
Amphipoda	H > A	U > M, L	U > M, L	(H > A)	—	U > M, L	—	U, M > L	—
Cornis sp.	—	L > M > U	L > M > U	—	—	—	—	L, M > U	L, M > U
Callibaetis sp.	—	—	L, M > U	—	—	—	—	—	—
Coenagrionidae	H > A	—	—	—	Not Analyzed	—	—	—	L, M > U
Chironomidae	H > A	—	L, M > U	—	—	—	A > H	—	—
Gyraulus sp.		Not Analyzed		A > H	—	—	—	—	—
Physa gyrina	H > A	—	U > M, L	H > A	—	—	—	—	—
				Pools					
Planariidae	—	—	—	—	U > M, L	—	A > H	—	—
Hirudinea		Not Analyzed			Not Analyzed		—	L > M, U	—
Amphipoda		Not Analyzed			Not Analyzed		A > H	—	—
Cornis sp.	—	L > M > U	—	—	L > M > U	L > M > U		Not Analyzed	
Callibaetis sp.	—	—	—		Not Analyzed			Not Analyzed	
Coenagrionidae	—	—	—	(A > H)	—	—	—	—	—
Chironomidae	—	L > M > U	L > M > U	—	—	—	A > H	—	—
Ceratopogonidae	—	—	—		Not Analyzed			Not Analyzed	
Gyraulus sp.	A > H	L > M > U	—	—	L > M > U	L > M > U	—	—	—
Physa gyrina	—	—	—	—	—	—	—	—	—

*H refers to heated channel; A to ambient channel; U to upper, M to middle, L to lower section of channel; — refers to no significance found.

†Not analyzed refers to the animal group numerically <1.0% of the total found.

‡Parentheses denotes significant differences only in portion of the channel.

Significant differences were at $P < 0.05$. Degrees of freedom for channel, location, channel X location are 1, 2, 2, and 60, respectively for winter and spring. Summer values are 1, 2, 2, 66. H > A means heated channel had a significantly higher density than ambient channel. L > M > U denotes an additional condition that a significant separation existed at each of the three locations. L > M, U refers to lower section having a significantly higher density than the middle or upper sections.

Table 3. Seasonal macroinvertebrate associations in the ambient and heated channels

Season	Ambient Channel Clusters			Heated Channel Clusters			
				Riffles			
Winter	Planariidae Isopoda Amphipoda (*Callibaetis* sp.)*	*Caenis* sp. *Physa* sp.	Coenagrionidae Chironomidae	Planariidae Amphipoda *Physa* sp.	*Callibaetis* sp. *Caenis* sp. Coenagrionidae	Isopoda (Chrionomidae)	
Spring	Planariidae Isopoda Amphipoda (*Callibaetis* sp.)	*Caenis* sp. Chironomidae *Physa* sp. *Gyraulus* sp.		Planariidae Isopoda Amphipoda	*Caenis* sp. *Callibaetis* sp.	Chironomidae *Physa* sp. *Gyraulus* sp.	
Summer	(Planariidae) (Isopoda) (Amphipoda) *Caenis* sp. *Gyraulus* sp.	(Coenagrionidae) Chironomidae *Physa* sp.	Hirudinea *Callibaetis* sp.	Planariidae Hirudinea Amphipoda	(Isopoda) *Caenis* sp. Coenagrionidae Chironomidae	*Callibaetis* sp. *Physa* sp.	*Gyraulus* sp.
				Pools			
Winter	Planariidae (*Physa* sp.)	*Caenis* sp. *Callibaetis* sp. Coenargionidae Chironomidae Ceratopogonidae *Gyraulus* sp.		(Planariidae) *Gyraulus* sp.	*Callibaetis* sp. Coenargionidae *Physa* sp.	Caenis Chironomidae	Ceratopogonidae
Spring	Planariidae Coenargionidae	*Caenis* sp. *Gyraulus* sp. Chironomidae	*Physa* sp.	(Planariidae) *Caenis* sp. Coenargionidae *Gyraulus* sp.	Chironomidae *Physa* sp.		
Summer	Planariidae Amphipoda Coenargionidae	(Hirudinea) Chironomidae *Physa* sp. *Gyraulus* sp.		Planariidae Coenargionidae Chironomidae *Physa* sp.	(Hirudinea) Amphipoda	*Gyraulus* sp.	

*Taxa in parenthesis were negatively associated with the other groups in the cluster.

cove with reproduction being continuous. The first found newly hatched-snails in the ambient-temperature cove occurred in June. In laboratory experiments, van der Schalie & Berry (1973) found few *Physa gyrina* snail eggs laid at 33°C; Sankurathri & Holmes (1976) found no eggs hatching at 32°C and slow embryonic development at 10°C. By comparison, newly hatched physids were found in our outdoor channels preceding and following the period of maximum water temperature.

Newly hatched isopods, *Asellus racovitzai* were found in the heated channel in February but not until May in the ambient channel. No isopods were recovered from the heated channel after June with water temperatures exceeding 30°C until the end of July. This contrasts with the conclusion of Langford (1972) who listed the European isopod, *Asellus aquaticus*, as a species highly tolerant to elevated temperatures. Andersson (1969) compared the life histories of *Asellus aquaticus* in a northern and central Swedish lake. The isopods in the central lake were univoltine while 2-years were needed to complete the life cycle in the northern lake. Isopod growth was reported to be directly proportional to degree days above 4°C with no growth at temperatures between 0 and 3°C.

Little information is available on the life history of the amphipod, *Crangonyx pseudogracilis*, to make comparisons. Bousfield (1958) has described this species complex as a spring and summer breeder. By contrast, gravid females of this species were found in both channels from the winter into the summer months. A related species, *Crangonyx gracilis*, (Martein & Benke, 1977) has a life span of 1-year in Georgia and breeds from February to October.

This study has shown that the life history and abundance of macroinvertebrates were seasonally altered in outdoor systems elevated 10°C above ambient over several seasons. Because of the length of this study (<1 year), it is not possible to propose optimum thermal regimens for macroinvertebrates. Rather our study demonstrates that many normal seasonal biological events within an ecosystem can be altered by water temperature changes and supports the suggestion by Langford (1972) that cooling treatment may at times be necessary for discharged water elevated near 10°C where major portions of river flows are utilized.

Acknowledgements—The authors want to thank John T. Shyne, Kathleen J. Nordlie, Sean J. Hancock, Nancy A. Cassano, Terry W. Howey, Robert D. Edstrom, and Barbara A. Poeschl for their valuable assistance. Dr David R. McConville and students at St Mary's College, Winona, MN (EPA Contract 68-03-2453) performed the macroinvertebrate sample counts. Tom Henry provided the water and temperature control for the outdoor test system. Dr E. L. Bousfield performed the amphipod identifications and Dr Thomas E. Bowman the identification of isopods. We thank Drs K. E. F. Hokanson and R. J. Hall for critically reviewing the manuscript.

REFERENCES

Andersson E. (1969) Life-cycle and growth of *Asellus aquaticus* (L.) with special reference to the effects of temperature. *Rep. Inst. Freshwat. Res. Drottingholm* **49**, 5–26.

APHA (1975) *Standard Methods for the Examination of Water and Wastewater*. 14th edition American Public Health Association, Washington DC.

Bousfield E. L. (1958) Fresh-water amphipod crustaceans of glaciated North America. *Can. Field-Natural.* **72**, 55–113.

Bush R. M., Welch E. B. & Mar B. W. (1974) Potential effects of thermal discharges on aquatic systems. *Envir. Sci. Technol.* **8**, 561–568.

Coutant C. C. (1962) The effect of a heated water effluent upon the macroinvertebrate riffle fauna of the Delaware River. *Proc. Penn. Acad. Sci.* **36**, 58–71.

Curry L. L. (1965) A survey of environmental requirements for the midge (Diptera: Tendipedidae). In *Biological Problems in Water Pollution* (Edited by Tarzwell C. M.), pp. 127–141. U.S. Dept. Health, Education and Welfare, Publ. Health Serv., Cincinnati, OH.

De Witt R. M. (1955) The ecology and life history of the pond snail. *Physa gyrina. Ecology* **36**, 40–44.

Durrett C. W. & Pearson W. D. (1975) Drift of macroinvertebrates in a channel carrying heated water from a power plant. *Hydrobiology* **46**, 33–43.

Elliott J. M. (1971) Some methods for the statistical analysis of samples of benthic invertebrates. *Freshwat. Biol. Ass.* Scientific Publ. No. 25.

Gray L. J. & Ward J. V. (1979) Food habits of stream benthos at sites of differing food availability. *Am. Mid. Natural.* **102**, 157–167.

Hopwood A. J. (1974) Thermal effects of a nuclear power plant on the Mississippi River at Monticello, Minnesota. Water Resources Research Center, University of Minnesota, Minneapolis, MN. Bulletin No. 69.

Koosman V. W. & Newburg H. J. (1977) Modification of the water flotation method for separating organisms from detritus in benthic samples. *Prog. Fish Cult.* **39**, 189–190.

Langford T. E. (1972) A comparative assessment of thermal effects in some British and North American Rivers. In *River Ecology and Man* (Edited by Oglesby R. T., Carlson C. A. & McCann J. A.), pp. 319–351 Academic Press, New York.

Martien R. F. & Benke A. C. (1977) Distribution and production of two crustaceans in a wetland pond. *Am. Mid. Natural.* **98**, 162–175.

Miller M. C., Hater G. R., Federle T. W. & Reed J. P. (1976) Effects of power-plant operation on the biota of a thermal discharge channel. In *Thermal Ecology II* (Edited by Esch G. W. & McFarlane R. W.), pp. 251–258. ERDA Symposium Series 40, Tech. Info. Center, Augusta, GA.

National Academy of Sciences & National Academy Engineering (1973) Water Quality Criteria 1972, EPA-R3-73-033, Washington, DC.

Neter J. & Wasserman W. (1974) *Applied Linear Statistical Models. Regression, Analysis of Variance, and Experimental Designs*. Richard D. Irwin, Inc., Homewood, IL.

Nie N. H., Hull C. H., Jenkins J. G., Steinbrenner K. & Bent D. H. (1975) *Statistical Package for the Social Sciences*, 2nd edition. McGraw–Hill, New York.

Rabeni C. F. & Minshall G. W. (1977) Factors affecting microdistribution of stream benthic insects. *Oikos* **29**, 33–43.

Sankurathri C. S. & Holmes J. C. (1976) Effects of thermal effluents on the population dynamics of *Physa gyrina* Say (Mollusca: Gastropods) at Lake Wabamun, Alberta. *Can. J. Zool.* **54**, 582–590.

Stefan H. G., Gulliver J., Hahn M. G. & Fu A. Y. (1980)

Water temperature dynamics in experimental field channels: analysis and modeling, St. Anthony Falls Hydraulic Laboratory, Project Report No. 193, University of Minnesota, Minneapolis, MN.

Surber E. W. & Bessey W. E. (1974) Minimum oxygen levels survived by stream invertebrates. Virginia Polytechnic and State University, Blacksburg, VA. Bulletin No. 81.

van der Schalie H. & Berry E. G. (1973) Effects of temperature on growth and reproduction of aquatic snails. EPA-R3-73-021, Washington, DC.

Wrenn W. B., Armitage B. J., Rodgers E. B., Forsythe T. D. & Granneman K. L. (1979) Browns Ferry biothermal research series. II. Effects of temperature on bluegill and walleye, and periphyton, macroinvertebrate, and zooplankton communities in experimental ecosystems. EPA-600/3-79-092, August, Duluth, MN.